[Team Green Heaters; Gabriel Brian-Grebot, Sophia Drimmel, Nicolas Haug, Vlad Panait, Patrick Mayer; Waste heat from data centers: from problem to solution– Umweltinstitut]

Mission Statement of [*Team Green Heaters*]

[please answer the following questions in full sentences. Use references, if necessary. This mission statement will be included in your final report.]

1. **What problem do we solve?**

We are addressing the question of how much waste heat is produced by data centers in Germany, how it can be efficiently reused, the challenges data centers face in reusing this heat, and how existing and future regulations can influence its reuse. Our goal is to find solutions to harness the high potential of waste heat produced by data centers in Germany.

2. **Who is our audience?**

Our primary audience is the Umweltinstitut and Mr. Burtscher, as they presented us with this challenge. However, from a broader perspective, our audience includes all data centers in Germany, the German government, and various other companies and regulators who could benefit from the efficient reuse of waste heat.

3. **What makes us as a team unique?**

What makes our team unique is our multicultural composition, with members from Germany, France, and India. We also come from diverse academic backgrounds, ranging from politics and design to engineering, with affiliations to both TUM and HM. This diversity allows each team member to contribute unique perspectives and insights, enabling us to discuss and generate innovative solutions.

4. **What is our intended contribution or impact?**

Our intended contribution or outcome of this project is to provide an overview of the current status of waste heat from data centers in Germany. This includes presenting gross figures on the amount of waste heat produced and reused, highlighting the challenges in reusing waste heat, and showcasing potential use cases for its reuse. Additionally, we will analyze current regulations and offer recommendations for regulatory improvements to enhance the current situation.

5. **In order to make a successful contribution, our next steps are:**

We will conduct further research and reach out to experts and companies in various fields to gain a holistic overview of the current status. We will then discuss the potential applications of our findings during the workshop week.

6. **Our vision for the future is:**

While it would be ideal to envision all waste heat being recovered and all cities and companies heated by it, a more realistic vision for the foreseeable future would be to significantly increase the percentage of reused waste heat, by addressing the current technical and political challenges.

Introducing our challenge we want to give a short overview of the current status of data centers in Germany, including technical aspects and new legislations.

Current situation:

A recent study by the German Datacenter Association e.V. offers estimated data on the data center landscape in Germany. Currently, there are 1,994 data centers with an IT power above 50 kW. Of these, 309 are colocation data centers, accounting for 69% of the total IT power of 1,955 MW in Germany. (German Data Center Association 2024) Their energy consumption, approximately 20 billion kWh, represents 2-3% of Germany's total consumption, and this number is on the rise. (Hintemann et al. 2023) With 90% of this energy potentially recoverable, there is significant potential for reuse. (Lou et al. 2019) This potential is reflected in the growing awareness of the need to create regulatory frameworks.

In Germany, the Energieeffizienzgesetz was implemented in 2023 in order to improve the energy efficiency and reduce the primary and final energy consumption, as well as the import and use of fossil fuels (Energieeffizienzgesetz 2023). This law includes specific requirements for energy efficiency and waste heat, along with information obligations for operators (Energieeffizienzgesetz 2023). Until July 1, 2025 data centers are required to create an energy or environmental management system. From January 1, 2026, data centers with a capacity of 300 kilowatts or more must provide validation or certification of their energy or environmental management system.The regulation also applies to new data centers, requiring them to submit information to be collected in the Federal Government's Energy Efficiency Register (Energieeffizienzgesetz 2023). For climate-neutral data centers, those beginning operations on or before July 1, 2026, must be designed and operated to achieve an energy usage effectiveness (EUE) of 1.5 or less by July 1, 2027, and an EUE of 1.3 or less by July 1, 2030, on an annual average basis (Energieeffizienzgesetz 2023). The Energieeffizienzgesetz represents a significant legislative step in Germany's efforts to improve energy efficiency. However, the law currently applies to a limited number of data centers and allows for numerous regulatory exceptions.

On the other hand, the Wärmeplanungsgesetz targets another important actor in the heat waste discourse: municipalities. Municipalities are key stakeholders as they manage the local heat supply for infrastructure such as swimming pools. The Wärmeplanungsgesetz requires municipalities to develop detailed heat plans that assess current heat demand and supply (Wärmeplanungsgesetz 2023). Furthermore, the plans should include potential for energy savings and the use of renewable energy sources. Municipalities with more than 100,000 residents as of January 1, 2024, must submit these heat plans by June 30, 2026. All other municipalities must submit their plans by June 30, 2028 (Wärmeplanungsgesetz 2023). Waste heat can be a valuable renewable energy source, and it should be considered in these heat plans, as highlighted on the Wärmeplanungsgesetz website of the Ministry for Housing, Urban Development, and Building (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, n.d.). Consequently, the Wärmplanungsgesetz also creates pressure on the municipal and administrative side to include waste heat into their heat plans.

In summary, an interesting legislative situation can be observed, as two legislations are trying to initiate the efficient reuse. These two laws primarily focus on heating, prompting the question of whether heating is the only or the most efficient use case for waste heat from data centers.

A best-practice study by Bytes2Heat provides an overview of already existing waste heat reuse applications and also highlights potential areas for reuse (see Figure 1). Since the entire study is in German, we will highlight some possible applications. The most efficient and widely used application is the reuse of waste heat for directly heating nearby buildings. Heating buildings such as houses, hotels, or even clubs is a straightforward way to reuse waste heat, if not directly connected, facilitated by district heating networks. Beyond heating buildings, waste heat can also be used for cooling through absorption and adsorption cooling. Adsorption cooling is particularly effective for reusing heat during the summer months when heating demand is lower. Other summer applications include industrial and agricultural processes like desalination, eel farms, algae farms, greenhouses, and grain drying. (Bytes2Heat 2023)

Figure 1: Use cases for waste heat by data centers (Bytes2Heat 2023)

Despite these potential applications, the study only shows that there are very few applications yet. Why have so few been realized? What are the hindering factors?

Hindering factors for the reuse of waste heat

In a 2022 Bitkom survey, data centers named the following primary obstacles to implementing waste heat reuse

1. Lack of consumers for their waste heat
2. No commercial use possible
3. Waste heat temperatures are too low
4. High investment costs

(Hintemann et al. 2022)

These responses highlight three main issues: the disconnect between data centers and municipal heating networks, high costs, and temperature levels.

High costs and temperature levels

The issues of high costs and temperature levels are closely related. Data centers mostly use two cooling techniques: air cooling and liquid cooling. The temperature of waste heat from air-cooled data centers ranges from 15-30°C, whereas liquid-cooled data centers produce waste heat between 50-60°C. Most applications require temperatures above 50°C, making liquid-cooled data centers more viable for waste heat reuse. Waste heat recovery from air-cooled data centers is possible, but needs the application of heat pumps, which incurs high initial and operational costs, often making reuse financially unfeasible. (Yuan et al. 2023)

Liquid cooling, although more promising due to its higher potential for waste heat reuse and lower energy and water consumption, is not widely adopted. Only 31% of colocation data centers and 8% of enterprise data centers use liquid cooling. (German Datacenter Association 2024) This is primarily because air cooling is the traditional technology, making retrofitting costly. Additionally, liquid cooling requires specialized expertise and more complex maintenance, further increasing costs. (Ostler 2024) Colocation data centers face unique challenges due to their contractual arrangements, where tenants have little incentive to support infrastructure changes. (Chi et al. 2021) Therefore, liquid cooling is typically used only when necessary, primarily in high-performance computing (HPC) data centers that require superior cooling capabilities. (Ostler 2024)

Missing connection:

The lack of connection between data centers and municipal heating networks is another significant barrier. Recent legislation aims to bridge this gap, but the main issue remains the lack of publicly available data, as most of the relevant information, like the location or IT power of data centers is private and mostly only available through payment or subscription, hindering efficient implementation.

Data of waste heat in Germany

To tackle the challenge of missing data we created a MATLAB script calculating the waste heat for different scenarios. The script is based on the current state of the art and combines results and data from various studies. The script provides the amount of waste heat produced, the amount of reusable waste heat produced, the amount of waste heat reused and the percentage of waste heat reused for the following six scenarios. The results are shown in table 1.

1. Waste heat is equally recovered from liquid and air cooled data centers with ideal ERF for district heating
2. waste heat is mostly recovered by liquid cooled data centers, as they have a higher potential in reuse with ideal ERF for district heating
3. Waste heat is equally recovered from liquid and air cooled data centers with realistic ERF
4. Waste heat is mostly recovered by liquid cooled data centers, as they have a higher potential in reuse with realistic ERF
5. Waste heat is equally recovered from liquid and air cooled data centers with ideal ERF for reuse right at the data center e.g. heating of building
6. Waste heat is mostly recovered by liquid cooled data centers, as they have a higher potential in reuse with ideal ERF for reuse right at the data center e.g. heating of building

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
produced waste heat (billion kWh)	**18**	**18**	**18**	**18**	**18**	**18**
reusable waste heat (billion kWh)	**8.49**	**8.49**	**8.49**	**8.49**	**10.92**	**10.92**
waste heat reused (billion kWh)	**2.01**	**2.72**	**0.29**	**0.49**	**2.58**	**3.53**
percentage of total waste heat reused	**11.16%**	**15.12%**	**1.64%**	**2.74%**	**14.36%**	**19.56%**

Table 1: Results from MATLAB script for different scenarios (current status)

Based on this script we additionally wanted to create a map showing the energy consumption of data centers around Germany, highlighting the hotspots of potential heat waste to be reused. To do so, we tried to gather the limited publicly available data from multiple websites of colocation data centers in Germany. We managed to gather the total critical power of 100 colocation data centers across Germany, enabling us to give an estimate of their energy consumption per year.

Knowing that the data we used to create the map is not accurate and may not be representative of the data centers population in Germany, we chose not to display the scale of the concentration of the total critical power on the map. This map helps us to identify the cities with the most potential of heat waste reuse. We can easily spot Frankfurt, Berlin, Munich and Hamburg as the cities with the most potential.

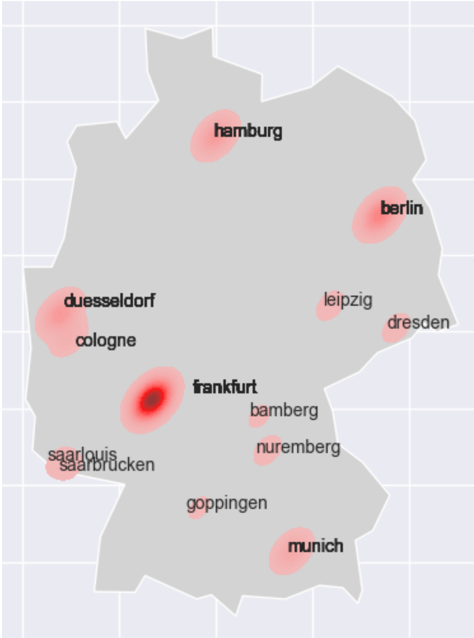

Figure 2: Heat map of the concentration of total critical power of 100 data centers in Germany

Recommendations to improve current status

Based on the data we found and the current legislation, highlighted above, we thought about recommendations that could improve the current status.

Our challenge partner, the Umweltinstitut e. V., has already issued a statement highlighting some important areas for improvement in the Energieeffizienzgesetz. They note that efficiency goals should be even more ambitioned and expanded until 2045, also the implementation has to be made mandatory. Data centers should use technology of the highest standard and try to align efficiency metrics with the current top runners of new data centers, for example by applying water instead of air cooling. These energy efficiency measures also have to be mandatory for smaller data centers. With the current regulations only about 1% of data centers would be subject to this policy. The goals for the energy reuse factor (ERF), the actual reuse of generated waste heat, must be more ambitious. Currently a reuse of 20% is mandated in the future, the Umweltinstitut proposes an ERF of 40% by 2030. Furthermore there are factors preventing data centers from making their waste heat available for reuse that should be tackled from an economic and legal standpoint. Lastly there is the demand for a higher accountability pertaining to the legislation. Data centers should be submitted to a maximum of data transparency and face sanction based on their profit in case of violations of regulations. (Umweltinstitut München e.V., 2023)

Taking these opinions into account we crafted additional suggestions for amending the EnEfG and the Wärmeplanungsgesetz. These are especially aimed to facilitate cooperation between data centers and cities or municipalities:

- We recommend a clearly defined intermediary to facilitate this cooperation
- We propose mandatory data transparency for data centers, including smaller ones that are currently not regulated by the Energy Efficiency Act
- There has to be an increase in incentives and funding for waste heat recovery projects at the local level opens up new opportunities for heat recovery
- We require data centers to consider heat recovery when planning new sites

- New build data centers should use liquid cooling, as it has lower energy consumption and better waste heat reuse potential
- The use of “cold heat networks” should be considered, as it creates the potential to reuse the low temperature waste heat from air cooled data centers

Implementing these recommendations would provide a solid basis for cooperation between data centers and cities or municipalities to the benefit of all stakeholders.

Suggested map for cooperation

To effectively present our findings and strategic recommendations, our team developed a prototype of a possible interactive map. This tool is essential for understanding and planning the distribution and utilization of waste heat from data centers across Germany.

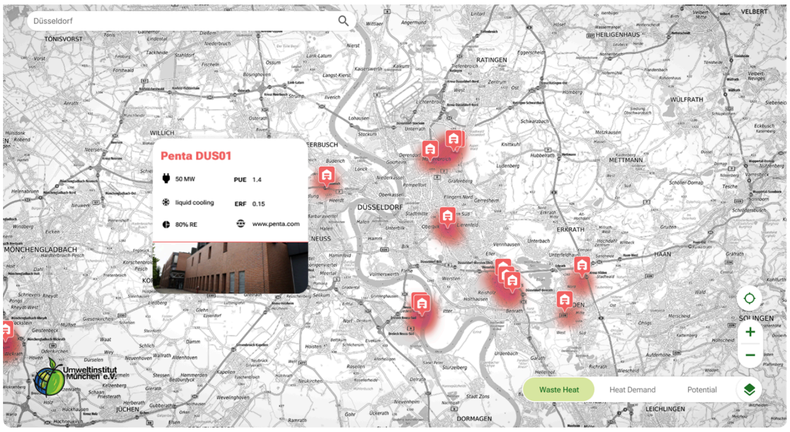

Figure 3: Heat map overlay of available waste heat in Düsseldorf

The first layer (figure 3) of our interactive map displays the available waste heat from data centers, marked by red pins across the region. By clicking on these pins, users can access detailed information about each data center, such as location, capacity, and amount of waste heat available. The red-shaded areas on the map mark regions with high availability of waste heat, providing a clear visual representation for municipalities and planners. This enables them to consider these renewable heat sources in urban planning and development, particularly in the zoning of new commercial or residential areas. The underlying data for this overlay was generated using a custom script, which calculated the waste heat potential.

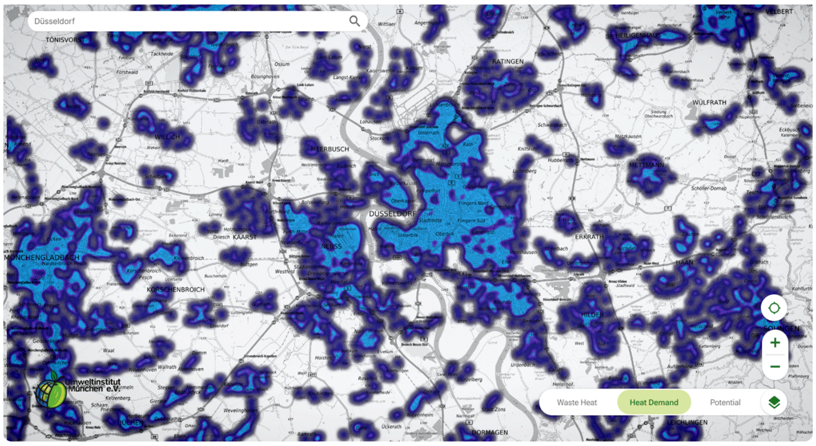

Figure 4: Heat map overlay of heating demand in Düsseldorf

The second overlay (figure 4) illustrates the heat demand within various regions, color-coded in blue. This map layer utilizes publicly available demographic and industrial data to estimate the heat demand based on population density and industrial activity, highlighting areas with potentially high demand for heating. The purpose of this overlay is to identify locations with a high amount of heating demand from residential and industrial sectors.

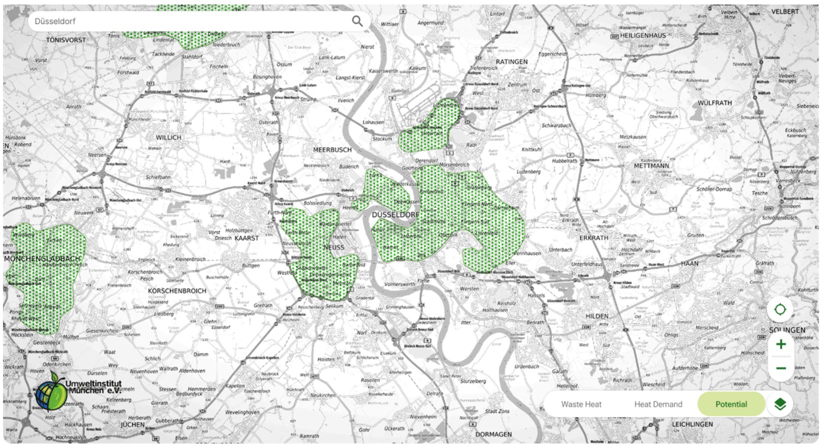

Figure 5: Heat map overlay of heating demand in Düsseldorf

Combining insights from the waste heat and heat demand layers, the third overlay (figure 5) focuses on potential areas for the establishment of new data centers or the expansion of existing ones. This green overlay identifies zones where no current waste heat sources are present but where there is significant demand for heat. This is crucial for data center operators and investors by indicating optimal locations for new facilities that could contribute to and benefit from local heat recovery initiatives. Future enhancements for this overlay might include detailed information on existing heat infrastructure capabilities and locations of experts who could assist in adapting facilities for integrating waste heat recovery solutions.

Each overlay on the map not only serves a unique purpose but is also integral to our strategic recommendations for both current and future data center operations. The interactivity and data-rich features of the map make it an essential tool for stakeholders, including data center owners, municipal planners, and policy makers, to make informed decisions about energy use and infrastructure development.

As we look to the future, further refinements could include real-time data updates, enhanced user interaction features, and expanded datasets to cover more geographical areas or additional types of infrastructure.

Appendix:

Script:

see separate attachment (waste heat script)

Sources:

Umweltinstitut München e.V. (2023, 11. April). Stellungnahme des Umweltinstitut München e.V. zum Gesetz zur Steigerung der Energieeffizienz (EnEfG) [Pressemeldung].

German Datacenter Association. (2024). Data Center Impact Report Deutschland 2024.

Hintemann, R., Hinterholzer, S. & Seibel, H. (2023). Bitkom-Studie Rechenzentren in Deutschland: Aktuelle Marktentwicklungen – Update 2023. Berlin: Borderstep Institut

Luo, Y., Andresen, J., Clarke, H., Rajendra, M., & Maroto-Valer, M. (2019). A decision support system for waste heat recovery and energy efficiency improvement in data centres. Applied Energy, 250, 1217-1224.

Bytes2Heat (2023). Best-Practice-Übersicht. Von inspirierenden Projekten zur Abwärmenutzung aus Rechenzentren lernen. https://www.bytes2heat.de/bestpractices

Hintemann, R., Hinterholzer, S., Graß, M. & Grothey, T. (2022). Bitkom-Studie: Rechenzentren in Deutschland 2021 – Aktuelle Marktentwicklungen. Berlin: Borderstep Institut.

Yuan, X., Liang, Y., Hu, X., Xu, Y., Chen, Y., & Kosonen, R. (2023). Waste heat recoveries in data centers: A review. Renewable and Sustainable Energy Reviews, 188, 113777.

Ostler, U. (2024, April 12) #30: Wasser als Kühlmittel im Rechenzentrum, im Server, besitzt viele Vorteile - und Vorurteile. DataCenter Diaries. https://player.captivate.fm/episode/6e9b410f-04d4-4eb6-b810-7268e7c073cf

Chi, C., Zhang, F., Ji, K., Marahatta, A., & Liu, Z. (2021). Improving energy efficiency in colocation data centers for demand response. Sustainable Computing: Informatics and Systems, 29, 100476.

Lechner, S., Paul, A., Völzel, C., Hintemann, R., & Hinterholzer, S. (2023). Innovative Abwärmenutzung aus Rechenzentren in Hessen am Beispiel von Offenbach.

Wärmeplanungsgesetz [Heat Planning Act], 20 December 2023, Bundesgesetzblatt 2023 I, Nr. 394.

Energieeffizienzgesetz [Energy Efficiency Act], 13 November 2023, Bundesgesetzblatt 2023 I, Nr. 309.

Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen. (n.d.). Kommunale Wärmeplanung. Retrieved June 17, 2024, from https://www.bmwsb.bund.de/Webs/BMWSB/DE/themen/stadt-wohnen/WPG/kommunale-waermeplanung.html